# VERIFYING THE EFFICACY IN REMOVING NUTRIENTS USING WASTEWATER TREATMENT STATIONS BY CONSTRUCTED WETLANDS

## *VERIFICAÇÃO DA EFICIÊNCIA DE REMOÇÃO DE NUTRIENTES EM ESTAÇÕES DE TRATAMENTO DE ESGOTO POR LEITO DE MACRÓFITAS*

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ABSTRACT: Due to the difficult access to conventional systems of collection and sewage treatment in low income rural communities, there is the need for low cost alternative technologies to treat such effluents. This study aimed to verify the efficacy of sewage treatment systems by constructed wetlands in the removal of the nutrients: nitrogen (N), phosphorus (P), calcium (Ca) and Magnesium (Mg), in two wastewater treatment stations (WWTS) located in a school and in a family house in small communities in the city of Irati/Brazil. Results revealed a good performance in the removal of the nutrients N and P in both systems, 75% and 37% for the house and 41% and 69% for the school, respective; which is associated to the plant uptake ability. However, the index of Ca and Mg presented significant increase, with 156% and 88% for the house and 165% and 128% for the school effluent, respectively, due to the use of gravel (rich in Ca and Mg) in the filter composition.

Keywords: Basic sanitation; domestic effluents; nutrients; constructed wetlands.

*RESUMO: Diante da dificuldade de acesso aos sistemas convencionais de coleta e tratamento de esgoto em comunidades rurais de baixa renda, buscam-se tecnologias alternativas de baixo custo para o tratamento desses efluentes. O presente trabalho teve como objetivo verificar a eficiência de estações tratamento de esgoto por leito de macrófitas na remoção dos nutrientes nitrogênio (N), fósforo (P), cálcio (Ca) e magnésio (Mg), em duas estações de tratamento, localizadas em uma escola e uma residência, de uma comunidade rural do município de Irati/Brasil. Foram observados bons índices de remoção dos nutrientes N e P para ambos os sistemas, respectivamente de 75% e 37% para efluente da casa e 41% e 69% para o efluente da escola, que estão associados à capacidade absorção pelas plantas. Em contrapartida, para Ca e Mg, os índices sofreram acréscimos elevados, com percentuais respectivamente, de 156% e 88% para efluente da casa e 165% e 128% para o efluente da escola, devido à utilização de pedra brita (rica em Ca e Mg) no preenchimento do filtro.*

*Palavras-chave: Saneamento básico; efluente doméstico; leito de macrófitas; nutrientes.*

# 1. INTRODUCTION

In Brazil, only 17% of the rural permanent houses have a general sewage and septic tank system (IBGE, 2011), that is, less than a fifth of Brazilians who live in the country do not have an efficient system of collection and treatment for the sewage generated. This fact directly reflects on these areas inhabitants' health. In such cases, the sewage treatment systems by root zone stations (wetlands) might be an efficient alternative to the wastewater treatment (Lesage *et al.*, 2007) in regions which do not have the conventional systems treatment.

In the sewage treatment by "constructed wetlands", the raw sewage initially goes through a septic tank (primary treatment) with the aim to remove coarse solid; then, the effluent is taken to the system by root zone stations for the secondary treatment (Schirmer & Oliveira, 2010; Van Kaick, 2002). These systems are based on natural processes (biological, chemical and physical) to remove the several pollutants, with the help of macrophytes and the filtering medium (Hill & Payton, 2000; USEPA, 2000; Ran *et al.*,2004).They present low construction and operation costs (Neralla *et al.*, 2000; Solano *et al.*, 2004), they can be built in the same place where the sewage is generated (Solano *et al.*, 2004) and they are efficient in the removal of heavy metals (Galetti *et al.*, 2010), organic matter (Klomjek & Nitisoravut, 2005), total coliforms (TC), *Escherichia coli* (*E. coli*), turbidity, chemical oxygen demand (COD) and nutrients, as phosphorus (P) (Schirmer *et al.*, 2009).

The chemical elements nitrogen and phosphorus (N and P) together with calcium (Ca) and magnesium (Mg), are essential minerals to the plants growth and production (Faquin, 2005; Campos, 2012). Through their root system, the plants absorb the necessary amounts of water and nutrients for their development (Faquin, 2005). A macrophyte present in the wetland system is able to assimilate such nutrients, which are present in the domestic wastewater (Pompêo, 2008). This change in nutrient concentration is due to a series of removal mechanisms (Schaafsma *et al.*, 1999; Tanner, 1996); from these, the most important is the uptake by the plant's root (Faquin, 2005; Ran *et al.*, 2004). Other mechanisms include, for instance, filtration, adsorption, absorption, gravity separation, combination of nitrification/denitrification (USEPA, 2000), decantation of suspended solids (Schaafsma *et al.*, 1999), etc.

This study aimed to evaluate the efficacy of two sewage treatment systems by root zone (in this case, constructed wetlands) based on the nutrient concentration analysis (N, P, Ca and Mg) before and after treatment in these stations. The elements like nitrogen and phosphorus, for instance, when improperly disposed and in excess might cause eutrophication in water bodies.

# 2. METHODOLOGY

This study evaluated two WWTS by root zone (constructed wetlands) located in small communities in the city of Irati (Paraná State, Brazil) one in a school (with around 230 students) and the other in a family house (with 5 residents).

Both WWTS evaluated were built with a vertical subsuperficial (and intermittent) flow system and are formed by three parts:

1) The root zone, where the species *Zantedeschia aethiopica* (calla lily) was planted;
2) The first filter (on which the calla lily is planted), formed by a 50 cm deep gravel nº 2 layer;
3) The second filter, formed by a 40 cm sand layer with granulometry varying from medium to coarse.

All the system is under an area that was made water proof with a plastic canvas (0.8 mm triple layer) whose aim is to prevent contamination of the soil and the groundwater near the system, as well as to prevent the effluent contamination with agents external to the station. The raw sewage coming from the septic tank gets to the wetland and the treated effluent, in this case, is caught by tubes which are below the sand layer. The house station was 1 m deep and 2.3 m wide x 2.5 m long; the school station, however, was 3.0 x 5.0 m width and length, respectively, 1.5 m deep.

Figure 1 shows the constructed wetland system scheme used both in the house and the school stations. Four campaigns were carried out in the period from April to August 2011. In each campaign 2 samples were collected, one upstream (after the septic tank) and the other downstream each root zone system, all in replicate. The collection was carried out respecting a minimum period of 48 hours after the last rain, in order to prevent sample dilution. The nutrient (N, P, Ca and Mg) concentration removal was analyzed. The sampling and analysis were carried out according to the *Standard Methods for the Examination of Water and Wastewater* (APHA, 1998).

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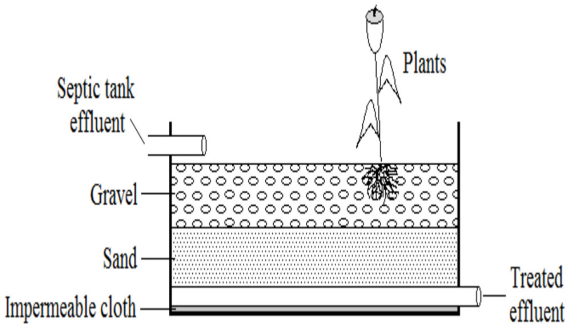


**Figure 1** - Sewage treatment system by root zone (scheme).

For the remaining nutrients (Ca and Mg), samples were acidified with diluted hydrochloric acid (pH<2.0) in high density polyethylene (HDPE) bottles and stored at low temperature (4°C). In the laboratory, samples were digested (perchloric acid digestion) and analytical determinations were carried out through atomic absorption spectrometry with flame atomization (AAS-flame).

# 3. RESULTS

## 3.1. Nitrogen

Nitrogen is present in the sewage in several forms due to its different oxidation states, and can be found in the organic or inorganic forms. The organic compounds might be amino acids, urea, uric acids, purines and pyrimidines (Philippi & Sezerino, 2004). In the inorganic form, the nitrogen can appear as ammonia ($NH_4^+$ and/or $NH_3$), nitrite ($NO_2^-$), nitrate ($NO_3^-$), nitric oxide (NO), nitrous oxide ($N_2O$) and gaseous nitrogen ($N_2$) (Olijnyk, 2008; Philippi & Sezerino, 2004).

In order for the complete removal of nitrogen present in the effluent to occur, a sequence of processes is necessary:ammonification, nitrification and denitrification (VanKaick, 2002). In the nitrification process, the presence of dissolved oxygen (DO) is an essential condition (USEPA, 1993), different from the denitrification, which requires anaerobic conditions to exist (Van Kaick, 2002; Valentim, 2003; Mota & VonSperling, 2009). In low nitrogen concentrations, assimilation by the plants is one of the processes which is also present (Van Kaick, 2002); when the nitrogen is caught by the plants, oxygen is released around their roots, providing the effluent treatment (Valentim, 2003).

Table 1 shows the $NH_3$ and dissolved oxygen (DO) values of the input effluent (output of the septic tank) and the wetland output in both places under evaluation and for the four campaigns carried out.

The level of nitrogen removal was on average 75.1% for the house effluent and 40.7% for the school effluent along the four campaigns. However, DO content in the effluent increased significantly 615.3% on average for the house effluent and 384.7% for the school effluent. It could be seen that the system implemented in the house had the best nitrogen removal and, also, the highest DO increase.

The plants are able to transfer, release and move oxygen efficiently through their root system, forming aerobic sites around their roots and rhizomes (Silva, 2007; Fia, 2009; Stottmeister *et al.*, 2003; Brix, 1997; Maltais-Landry *et al.*, 2009). Thus, the increase in DO concentrations in the effluent under study might be related to the transport occurred, which promoted simultaneously a nitrogen uptake by the plant. The process through which the nitrogen total removal (denitrification) would occur could not be confirmed, as neither of the systems offered the necessary anaerobic conditions, confirming the function of the plant in the system. It is also assumed that lower levels of nitrogen removal in the school might be related to higher loads applied in that system (due to the higher number of toilet users), reducing the hydraulic retention time; thus, the system implemented in the school suffered a nutrient overload, being prevented from promoting removal at a sufficient level. Despite the good $NH_3$ removal levels provided, these were not enough to attend the current Brazilian regulation, which determines a maximum value of 20 mg $L^{-1}$ for the release of ammonium nitrogen total in water bodies (CONAMA, 2011), in any of the campaigns (including the house).

In Lim *et al.* (2001) study, a subsurface-flow constructed wetland with cattail (*Typha latifolia*) received domestic sewage (after preliminary treatment) from students hostels and obtained removal indices of ammonium nitrogen ranging from 31% to 83%, confirming that the processes involved in this removal are the nitrification/denitrification and plant uptake.

## 3.2. Phosphorus

Plants assimilate phosphorus as phosphate ion ($PO_3^{4-}$) directly from the water and soil (higher affinity), and this element is also essential to the plants (Van Kaick, 2002). Other removal mechanisms of phosphorus in the effluent might occur involving the phenomena precipitation, sedimentation and mainly, the adsorption (Philippi & Sezerino, 2004).

Table 2 shows the total phosphorus value from the input and output effluent in the wetland in both places

**Table 1** – $NH_3$ and DO values at constructed wetlands, the input and output in the school and the house with removal percentage.

| $NH_3$ (mg $L^{-1}$) | House | | | School | | |
|---|---|---|---|---|---|---|
| | WWTS Input | WWTS Output | Removal (%) | WWTS Input | WWTS Output | Removal (%) |
| Campaign 1 | 86.0 | 14.0 | 83.7 | 152.0 | 124.0 | 18.4 |
| Campaign 2 | 101.0 | 32.0 | 68.3 | 172.0 | 26.0 | 84.9 |
| Campaign 3 | 149.7 | 45.6 | 69.5 | 225.4 | 149.2 | 33.8 |
| Campaign 4 | 116.7 | 24.8 | 78.7 | 244.4 | 181.4 | 25.8 |
| **DO 12C (mg $L^{-1}$)** | House | | | School | | |
| | WWTS Input | WWTS Output | Increase (%) | WWTS Input | WWTS Output | Increase (%) |
| Campaign 1 | 0.9 | 1.9 | 111.1 | 0.6 | 4.1 | 583.3 |
| Campaign 2 | 0.2 | 1.5 | 650.0 | 0.3 | 2.0 | 566.7 |
| Campaign 3 | 0.2 | 2.3 | 1,050.0 | 0.2 | 0.4 | 100.0 |
| Campaign 4 | 0.6 | 4.5 | 650.0 | 0.9 | 3.5 | 288.9 |

**Table 2** – Total phosphorus values for the input and output of the constructed wetlands for the school and the house and their removal percentages.

| Total Phosphorus | House | | | School | | |
|---|---|---|---|---|---|---|
| | WWTS Input | WWTS Output | Removal (%) | WWTS Input | WWTS Output | Removal (%) |
| Campaign 1 | 8.6 | 4.6 | 46.5 | 9.4 | 1.5 | 84.0 |
| Campaign 2 | 11.4 | 6.1 | 46.5 | 11.3 | 1.5 | 86.7 |
| Campaign 3 | 11.2 | 8.3 | 25.9 | 10.8 | 3.3 | 69.4 |
| Campaign 4 | 8.5 | 6.0 | 29.4 | 8.6 | 5.4 | 37.2 |

under evaluation throughout the four campaigns carried out.

The phosphorus removal indices were, on average 37.1% for the house effluent and 69.3% for the school effluent, unlike what had been verified in the nitrogen removal (Table 1), where higher removal percentage was obtained in the house. According to Gomes (1985), the phosphorus excess might reduce nitrogen assimilation. Thus, when the nitrogen removal values are compared to those for the phosphorus from the house effluent, the result is 75.1% and 37.1%; and from the school effluent 40.7% and 69.3%, respectively. Therefore, it was observed that in the house effluent, when there was good average level of nitrogen removal, the phosphorus removal was twice as lower. For the school effluent, the contrary was observed, once the phosphorus removal indices were higher (around 1.8 times higher), that is, the presence of phosphorus could in fact have inhibited the nitrogen removal from the medium. The presence of both elements in the effluent might have caused competitive inhibition in the plant uptake. In Kyambadde *et al.* (2004) study, active uptake and incorporation into plant tissue were the main factors responsible for the phosphorus removal (with indices of 88.8%), observed in constructed wetlands (CWs) planted with *Cyperus papyrus* for domestic wastewater treatment.

In addition, materials which are rich in calcium can effectively remove phosphorus from the wastewater, both by adsorption (of the support material) and phosphate precipitation (Fia, 2009; DeBusk *et al.*, 2004; Tanaka *et al.*, 2007). In this study, in which the system filter is filled with gravel, calcium release in the medium is likely to occur, and this might result in synergism between Ca and P (forming calcium phosphate), followed by precipitation and adsorption by the filter. This interaction between elements might be responsible for the decrease in phosphorus concentration in the effluent. However, it is still not certain which mechanisms prevail in the removal (precipitation, adsorption by filter or plant uptake, taking into consideration nitrogen inhibitions), whose contributions, very likely, vary according to each system conditions and configuration.

### 3.3. Calcium and Magnesium

Calcium and magnesium are essential elements to the plants and are absorbed in the forms $Ca^{2+}$ and $Mg^{2+}$, respectively; however, the presence of other ions, such as $K^{+}$ and $NH_4^{-}$, competitively inhibit Ca and Mg absorption (Faquin, 2005). According to Fia (2009), wetlands tend to present good calcium and magnesium removal indices; however, both elements can form insoluble compounds with phosphate (Fia, 2009; Van Kaick, 2002), which the wetlands are not able to remove effectively, and these are dissolved (added) in the effluent (Van Kaick, 2002).

Table 3 shows the Ca and Mg concentrations at the input and output of both constructed wetlands under study, as well as their percentage of removal.

The analyses show that there was increase in calcium concentrations at the WWTS output, on average 155.8% for the house effluent and 165.3% for the school effluent.

**Table 3** – Ca and Mg values for the WWTS input and output in the school and the house and their percentage of removal.

| Calcium (Ca) | House | | | School | | |
|---|---|---|---|---|---|---|
| | WWTS Input | WWTS Output | Increase (%) | WWTS Input | WWTS Output | Increase (%) |
| Campaign 1 | 4.6 | 13.2 | 186.9 | 3.7 | 13.0 | 251.3 |
| Campaign 2 | 6.3 | 17.0 | 169.8 | 3.7 | 10.8 | 191.9 |
| Campaign 3 | 4.0 | 9.9 | 147.5 | 4.9 | 8.5 | 73.5 |
| Campaign 4 | 4.2 | 9.2 | 119.0 | 3.6 | 8.8 | 144.4 |
| **Magnesium (Mg)** | House | | | School | | |
| | WWTS Input | WWTS Output | Increase (%) | WWTS Input | WWTS Output | Increase (%) |
| Campaign 1 | 2.2 | 4.8 | 118.2 | 1.6 | 5.8 | 262.5 |
| Campaign 2 | 3.2 | 5.7 | 78.1 | 2.0 | 4.4 | 120.0 |
| Campaign 3 | 2.2 | 3.9 | 77.3 | 2.0 | 3.2 | 60.0 |
| Campaign 4 | 1.9 | 3.4 | 78.9 | 1.8 | 3.1 | 72.2 |

Similarly to what occurred to calcium concentrations, the effluent presented magnesium concentrations higher than those found in the system affluent. Both in the house and the school WWTS there was, on average increase of 88.1% and 128.7% in magnesium indices, respectively. According to Silva (2007), the gravel used in the system filter suffers solubilization, thus increasing calcium and magnesium contents. This process might have triggered increase in the amount of dissolved salts in water, which by disassociating released high concentration of chemical elements, overcoming the absorption capability of the systems under study.

With the availability of these salts in the system due to the presence of phosphorus (observed in Table 2) the formation of insoluble compounds (calcium and magnesium phosphates) might also occur. These insoluble compounds formed do not allow plant uptake, and are then carried by the effluent (Van Kaick, 2002), thus increasing their concentration in the system output.

In a study by Guimarães *et al.* (2000), up to 40% increase was verified in the concentration of calcium and magnesium cations in the effluent, in which the wetlands received domestic sewage, had *Echinocloa cruz pavonese* and *Juncus sellovianus* planted and were filled with gravel n° 1. According to those authors, this increase was probably due to the organic matter mineralization process in the systems, which promoted increase in these salts in the final effluent. For Anjos (2003), the fact that these parameter concentrations were higher at the wetland output than at the input should be understood as a result of the competition with iron and manganese in the hydromorphic sediment, provoking dislocation of calcium and magnesium into the solution.

# 4. CONCLUSIONS

Taking into consideration the conditions of each system under study and the characteristics of the domestic sewage analyzed, from the results obtained in the sewage treatment system by root zone, the following could be seen:

1. Good nutrient removal indices, with percentages of 75.1% and 40.7% nitrogen and 37.1% and 69.3% phosphorus,respectively for the house and school, on average.
2. The main process involved in N removal indices seems to be plant uptake.
3. There is still uncertainty regarding the predominant process in P removal, which might be the plant uptake or the precipitation and adsorption by filtering.
4. The presence of both nutrients (N and P) in the effluent might have resulted in competitive inhibition in the system implemented at the school, therefore justifying the lower nitrogen removal indices in that place.
5. Even with good removal indices, it was not possible, in any campaigns, to meet the Brazilian environmental regulation requirements regarding the concentrations of total ammonium nitrogen in water bodies (maximum value 20 $mg.L^{-1}$, as set forth by the Environmental National Council – CONAMA).
6. For Ca and Mg, significant increase was seen in the concentration of the wetland output effluent. Percentages of 155.8% calcium and 88.1% magnesium in the house effluent and 165.3% calcium and 128.7% magnesium in the school effluent.
7. The gravel (component of the wetland system physical filter) is assumed to have suffered stabilization, resulting in the release of Ca and Mg dissolved salts in the effluent and, thus, overcoming the systems absorption capability and confirming the increase observed.
8. Dissolved salts, together with the phosphorus present in the effluent, might have formed insoluble compounds, which do not undergo plant uptake and, therefore are carried to the effluent.

In general, the constructed wetlands are suitable alternatives for wastewater treatment in small communities, which are distant from the collection and sewage treatment points. Besides being economically viable, these systems are easy to build and operate. Even the wetland being efficient to the sewage treatment, there is the need of further studies related to the physical-chemical and biological processes developed by the wetland (regarding the macrophyte performance), so that higher efficacy can be obtained.

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